CETA 82-05

Use of High Resolution Seismic Reflection and Side-Scan Sonar Equipment for Offshore Surveys

by

S. Jeffress Williams

COASTAL ENGINEERING TECHNICAL AID 82-05

NOVEMBER 1982

U.S. ARMY, CORPS OF ENGINEERS

COASTAL ENGINEERING RESEARCH CENTER

Kingman Building

Fort Belvoir, Va. 22060

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CETA 82-5	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) USE OF HIGH RESOLUTION SEISMIC REFLECTION AND SIDE-SCAN SONAR EQUIPMENT FOR OFFSHORE SURVEYS		5. TYPE OF REPORT & PERIOD COVERED Coastal Engineering Technical Aid 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) S. Jeffress Williams		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of the Army Coastal Engineering Research Center (CEREN-GE) Kingman Building, Fort Belvoir, Virginia 22060		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS C31665
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Army Coastal Engineering Research Center Kingman Building, Fort Belvoir, Virginia 22060		12. REPORT DATE November 1982 13. NUMBER OF PAGES 22
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Marine surveys
Seismic reflection equipment
Side-scan sonar equipment

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Continuous seismic reflection and side-scan sonar geophysical equipment were developed during and shortly after World War II primarily as military tools, but their application to marine geology and oceanographic research was quickly realized. In the past three decades electronics technology has greatly improved the capability of geophysical equipment to function as viable tools to decipher, in three dimensions, the geomorphology, subbottom structure, and geological character of marine, estuarine, and lake regions.

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Integrated survey programs using several seismic reflection systems and side-scan sonar in conjunction with grab-type and core sediment samples have been successfully used in many environments.

The Coastal Engineering Research Center (CERC) has been actively involved for the past two decades in collecting and analyzing nearly 10,000 line miles (16 093 kilometers) of geophysical profile data from 18 surveys over Atlantic, Gulf of Mexico, and Pacific Continental Shelf areas as well as the Great Lakes. The major objectives of this program have been to assess offshore sand and gravel resources and describe the geological character and evolution of each region. The geophysical equipment used, as well as specific techniques for use of the equipment and interpretation of the data, is described herein.

PREFACE

This report provides information on the development of seismic reflection and side-scan sonar equipment and the wide use of the equipment in surveys by the U.S. Army Coastal Engineering Research Center (CERC) for nearly two decades. Objectives of the investigation are to quantitatively assess offshore sand and gravel resources and study the geological and engineering character of U.S. marine and Great Lakes nearshore regions. This is the third and final report in a series prepared describing the procedures for carrying out sand resource surveys over Continental Shelf areas to locate potential sources of sand for beach nourishment. The first report (Prins, 1980) covered procedures for designing and conducting sand inventory surveys. The second report (Meisburger and Williams, 1981) dealt with use of the Alpine-type pneumatic vibratory coring device to retrieve long sediment cores. The work was carried out under CERC's Barrier Island Sedimentation Studies work unit, Shore Protection and Restoration Research Program, Coastal Engineering Area of Civil Works Research and Development.

The report was written by S. Jeffress Williams, Research Geologist, under the general supervision of Dr. C.H. Everts, Chief, Geological Engineering Branch, and Mr. N. Parker, Chief, Engineering Development Division.

Technical Director of CERC was Dr. Robert W. Whalin, P.E., upon publication of the report.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

Ted E. Bishop

TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

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U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

USE OF HIGH RESOLUTION SEISMIC REFLECTION AND SIDE-SCAN SONAR EQUIPMENT FOR OFFSHORE SURVEYS

by

S. Jeffress Williams

I. INTRODUCTION

In earlier times, when men were mapping the depth and morphology of the sea floor for navigational purposes or scientific interests, a simple line and weight were used. This method was often inaccurate and time consuming in deep water and areas of high current velocities. A major breakthrough came when acoustical echo sounders were developed during the 1920's. Echo sounders or fathometers measure the two-way traveltime of a high frequency acoustical pulse emitted from a survey vessel to the sea floor and its return to the surface. The traveltime is then converted, using the determined sound velocity, to precise water depths. During World War II, graphic paper recorders were added to sounders to yield a continuous profile of the bottom relief along a charted path of a survey vessel. Soon, improved sounders and recorders were being widely used, proving that the sea floor regions were far more varied and dynamic than had been previously supposed, and contained mountains, deep trenches, and broad continental shelves, along with features of smaller relief such as dunes and ridges.

Echo sounders operate at high frequencies (most commonly 30 to 200 kilohertz) and are effective in penetrating the water column, but in unconsolidated sediments the signal is quickly absorbed and does not penetrate much of the sediment. New technology following World War II produced higher power and lower frequency systems that penetrate the bottom sediments and yield a picture of their internal structure. These systems are termed *seismic reflection subbottom* profilers; a large variety of these have been widely used in the past three decades for oceanographic research, oil and gas exploration, and engineering site investigations.

Side-scan sonar is another line of equipment using a modified echo sounder that was developed during World War II to detect submerged enemy submarines. Side-scan sonar is an acoustical instrument that is normally towed behind a vessel and emits acoustical signals to both sides. The acoustical pulses are reflected from features on the sea floor and returned to the recorder to show even small-scale positive and negative relief of the sea floor. The differences in signal intensity are also found to be useful in identifying sea floor areas of different sediment composition.

Echo sounders, seismic reflection profilers, and side-scan sonar equipment are now widely used for many survey purposes in marine, estuarine, and lake environments. The geophysical equipment is vital to the exploration and geological analysis necessary for performing sand and gravel assessment studies; however, these studies are just one part of any survey effort. In general, the surveys conducted by the Coastal Engineering Research Center (CERC) are divided into five phases: (a) Planning and survey design; (b) geophysical data collection; (c) sea floor and subbottom sediment sampling; (d) laboratory analysis, data reduction, and interpretation; and (e) final report preparation and figure presentations. Both types of seismic reflection and side-scan sonar equipment are particularly useful in conducting surveys to locate and quantify sand and gravel resources, but they can also be used for many other purposes in any of several subaqueous environments.

II. APPLICATIONS OF SEISMIC REFLECTION AND SIDE-SCAN SONAR EQUIPMENT

CERC experience has shown that the major cost of any survey is leasing or purchasing a survey vessel and a precision navigation system. Therefore, it is cost effective to simultaneously use as many pieces of acoustical survey equipment as possible to maximize the geological and geophysical data available for interpretation. Echo sounders, side-scan sonar, and the various seismic subbottom profiling systems each provide slightly different but complementary data. When interpreted together these data yield an integrated, more meaningful and accurate picture of the geophysical and geological character of a survey site than if fewer data were used (Randall, 1980).

When deciding which types of survey equipment to use, it is important during the project planning phase to identify exactly what the study objectives are, and what features of the sea floor and subbottom are to be emphasized. As a general rule with seismic reflection and side-scan sonar equipment, good resolution of geological details is incompatible with deep penetration on seismic profiles, or wide lateral coverage with side-scan sonar. Thus, it is important to use as many pieces of equipment with overlapping capabilities as can possibly be operated from the survey vessel or are affordable. It is just as important to have highly trained and experienced personnel involved in all phases of the survey to insure proper interpretation of the geophysical data. Since the raw information on geophysical records does not often yield obvious conclusions, and therefore several interpretations are possible, highly trained and experienced personnel skilled in record interpretation are necessary to accurately reduce the data and derive synoptic descriptions of the survey area.

Navigation for Accurate Position Control.

The use of a navigational system that is capable of accurately determining the horizontal position of bottom and subbottom features recorded is important for any geophysical survey. For most nearshore surveys, the various electronic microwave range-range systems have been used most successfully. They are relatively trouble free, easy to operate, and are accurate to about 10 feet (3 meters). However, they are limited to line-of-sight range of about 100 miles (160 kilometers). LORAN-C is another system of navigation that is widely available and may be used; however, its accuracy is on the order of 600 to 1,500 feet (183 to 457 meters) depending on the geographical location. LORAN-C should be used only in broad reconnaissance surveys or when microwave systems are not available.

With any geophysical system, event marks should be put on the records at timed intervals corresponding to map longitude and latitude positions. Time spacing for the event marks will vary depending on the nature of the survey. For very accurate surveys with many geological features, event marks should be about 2 to 5 minutes apart; for straight tracklines, in relatively featureless areas, longer time intervals may be used. It is also important to keep in mind that the navigational system and the event marks on the records note the position of the vessel and not the position of seismic and side-scan equipment being towed astern. The distance from the navigational antenna to the towfish should be subtracted when plotting positions of features from the records onto maps.

III. CONTINUOUS SEISMIC REFLECTION PROFILING EQUIPMENT

1. Principles of Seismic Reflection Operation.

Seismic reflection systems all function similarly. Each has a sound source or transducer in the water that generates acoustical signals at regular power and frequency outputs, as well as a receiver in the water at a fixed distance from the source that picks up acoustical pulses reflected from the sea floor and from geological boundaries in the subbottom (Fig. 1). The reflected energy picked up by the receiver is then transmitted to a recorder on the survey vessel where it is graphically displayed to yield continuous seismic profiles. The profiles are analogous to geological cross sections. The acoustical reflections are printed out in relation to the traveltime needed for the transmitted signal to be reflected and returned to the receiver. However, an approximate vertical scale can be constructed by approximating sound velocities in water, and in the most common sediments encountered. For seawater, a value of 4,800 feet (1463 meters) per second is commonly used, while for unconsolidated sandy materials an average figure is 5,450 feet (1661 meters) per second. Sound velocities in sedimentary rocks tend to increase with the depth of burial below the sea floor, as well as with the rock age, and past influences such as glacial loading or subaerial exposure at times of lower sea level. Velocity is generally related to the relative density of the sediments, but other important factors affecting velocity are sediment porosity; the degree of compaction; grain

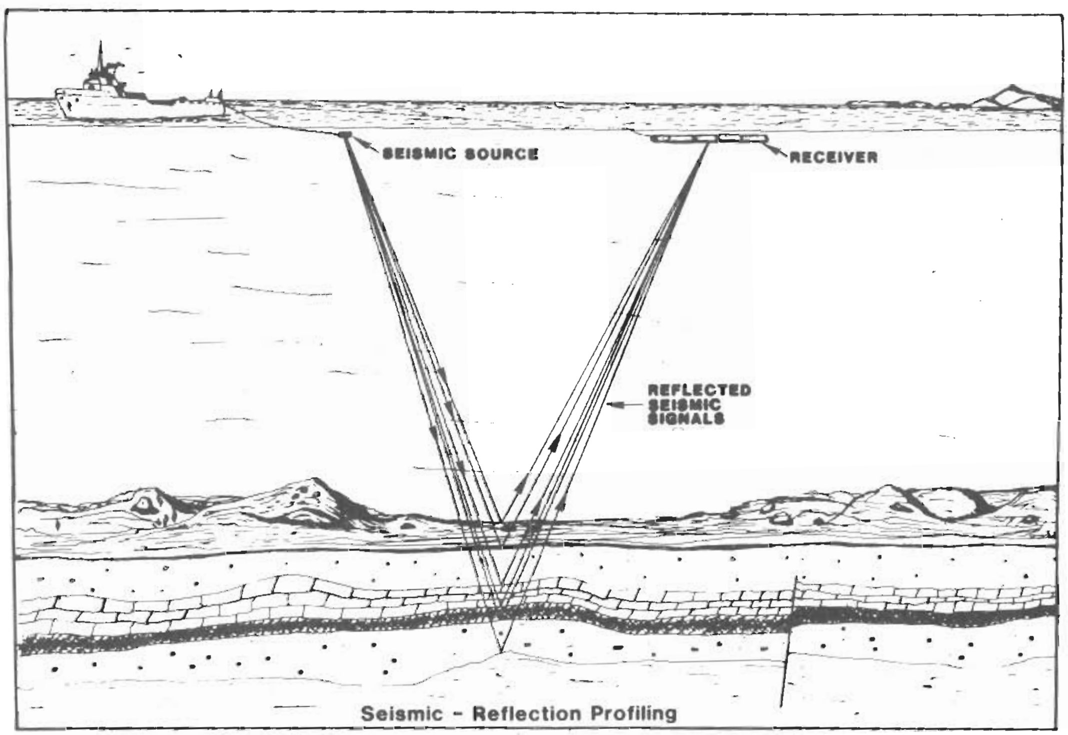


Figure 1. Schematic showing the principles of continuous seismic reflection profiling (from McClelland Engineers, Inc., 1981).

shape, orientation, and the degree of cementation; nature of grain-to-grain contact, and moisture content (Palmer, 1967; Van Overeem, 1978).

The amount of acoustical energy reflected from an interface depends largely on the impedance (sediment density times acoustical velocity) of the materials above and below the interface boundary. The greater the impedance differential, the stronger the resulting reflection will be. It is for this reason that the strongest reflection horizons on seismic profiles are the water sea floor boundary, contacts between compact sands and soft muds, organic-rich sediments with high concentrations of natural gas, and unconformities between recently deposited sediments and underlying hard bedrock.

2. Types of Energy Sources.

Since continuous seismic reflection equipment first came into wide use in the 1960's, a wide variety of different types and configurations have been developed. However, all the seismic devices consist of three basic components:

(a) An energy source or transducer that emits acoustical pulses at specific power and frequency levels;
(b) one or more receivers that pick up the transmitted acoustical "echoes" after they are reflected back from the seabed and subbottom; and
(c) a recording instrument that converts the reflected acoustical signals to electrical signals, which in turn are converted into a more permanent record (Palmer, 1967).

Seismic data are normally recorded on graphic strip chart-type profiles; however, the data may also be entered onto magnetic tapes suitable for computer processing and enhancement following the survey. There are of course many pieces of electronic equipment other than these three basic components but they are specific in function and a detailed discussion is beyond the scope of this report.

All seismic reflection profiler systems produce vertical profiles of the seabed and subsea floor geological character under the path of a moving survey vessel. However, each system yields a slightly different record of subbottom sediment penetration and degree of resolution, depending on the frequency and power of the emitted signal. A summary of the primary seismic systems is included in the Table. In general, higher power and lower frequency systems will penetrate farther into the sea floor subbottom but will have less resolution; whereas, a relatively low power and high frequency transducer will be able to resolve more detail of the subbottom bedding and geological character, but depth of penetration will be limited. A trade-off between frequency and power is always a problem; therefore, it is important to carefully match the selection of seismic equipment with survey objectives and needs. Another solution is to use several complementary geophysical systems simultaneously during a survey. For most seismic systems the best results are obtained when the seas or the swells are less than 3 feet (1 meter). Higher wave conditions will significantly deteriorate the quality of the seismic profiles.

a. Pinger System. The *Pinger* is a relatively high frequency (2 to 14 kilohertz), relatively low power piezoelectric transducer that is useful in bathymetric surveying and for delineating very fine detail of the sea floor and subbottom to depths of about 100 feet (30 meters) in softer materials (see Fig. 2). In areas where the seabed consists of firm fine-grained sand or semiconsolidated coastal plain strata, the pinger signal may not have enough power

Table. Characteristics of seismic profiling systems.

System	Frequency range	Power output (J)	Resolution (m)	Sediment penetration (m)	Application
Echo sounder	12 to 200 kHz	<0.5	0.1 to 0.2	Minimal	Measure accurate water depths and identify suspended mud areas.
Pinger	2 to 14 kHz	0.1 to 5	0.2 to 1	≤30	Measure water depths and provide very high resolution of the shallow subbottom.
Boomer	14 to 300 Hz	100 to 1500	0.5 to 2	⪅100	Measure approximate water depths and provide high resolution and moderate penetration of the subbottom.
Engineering sparker	200 to 1500 Hz	50 to 1200	1 to 2	⪅150	Especially useful in "hard bottom" sea floor areas to get moderate resolution and moderate penetration.

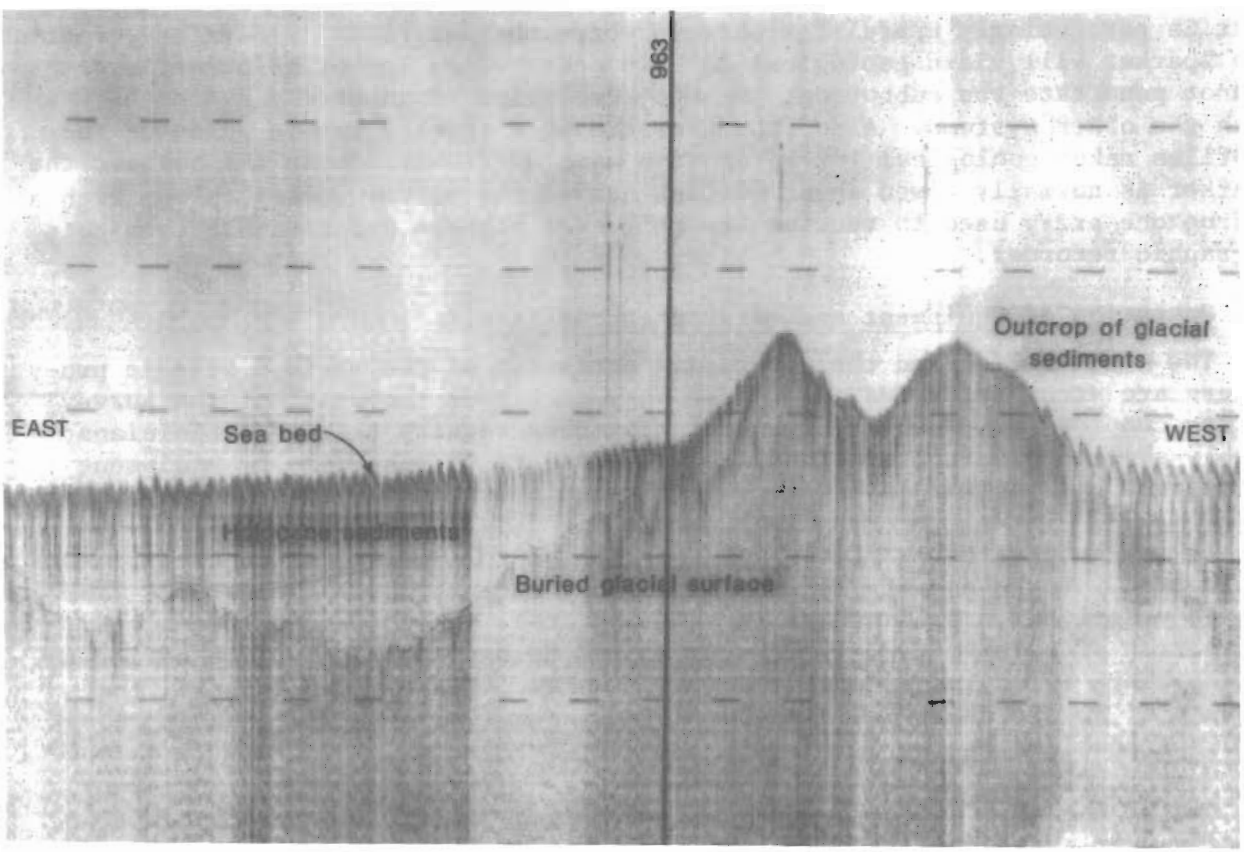


Figure 2. Example ORE Pinger (3.5 kilohertz) profile. Timing line interval is 5 milliseconds ≈7.5 meters in upper sediment layer.

to yield subbottom reflections. The pinger system is most commonly either fixed over the side of the survey vessel or towed behind. The former method is used most often on CERC's surveys because it lessens interference when other equipment is being towed from the vessels. A convenient feature of the pinger is that, unlike other seismic systems, the same transducer is used to both transmit and receive the acoustical signals, thus minimizing problems associated with equipment deployment and retrieval.

b. Boomer Systems. The boomer seismic systems (Fig. 3) use an electromechanical energy source having a variable power output from 100 to about 1500 joules depending on the particular system used. An advantage of boomer systems is that they yield high resolution of geological detail (Fig. 4) with subbottom penetration as great as 300 feet (91 meters). Almost no bubble pulse appears on the record to mask the data return in contrast to some sparker equipment; this is an advantage when interpreting the profiles. Since boomer profiles yield such detailed data on sedimentary bedding and contracts, they are especially useful in making correlations with cores and borings that may also be taken as part of a survey. Boomer transducers are normally towed about 30 feet (10 meters) behind and to the side of the survey vessel on a catamaran. The reflected signals are received by a 10- to 12-element "eel" or hydrophone that is towed to the opposite side. The seismic profile data are graphically displayed on a dry paper recorder.

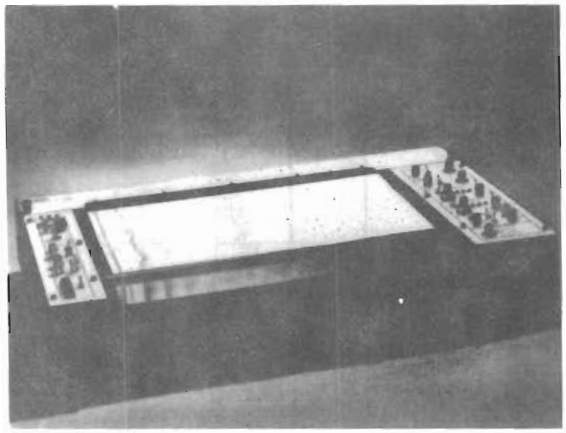
c. Engineering Sparker. The engineering sparker system, sometimes called a "minisparker," is an intermediate penetration, medium resolution device that is particularly useful for surveys where the sea floor is firm or compact. The sparker will yield geological data in areas where boomer or pinger systems cannot penetrate the subbottom, but the resolution is generally not as high as with the other systems. Also, the presence of a thicker bubble pulse on the profiles makes geological interpretation more difficult. Like the boomer, the sparker is normally towed about 30 feet behind the survey vessel, along with a hydrophone array used to receive the reflected signals and transmit them to a graphic recorder.

3. Operation of Equipment and Data Interpretation.

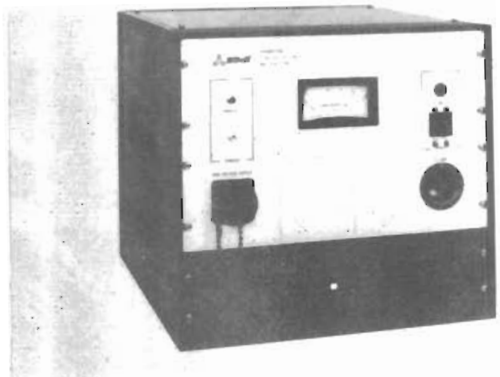
The mobilization and the day-to-day operation of the various seismic profilers are straightforward and do not vary much from the start of the survey to its completion. However, the operation does require trained technicians; a highly skilled electronic technician is necessary to take care of equipment breakdowns and regular maintenance of the equipment during the survey phase.

If the geophysical profiles are recorded on roll paper, as opposed to magnetic tape, at the end of each survey day the records should be removed from the survey vessel and stored ashore in a secure area. At the end of the survey, the collection of seismic profile records should be hand-carried to the office to insure there is no loss, damage, or undue delay. The records are the final product of an expensive and time-consuming survey--security in transit cannot be overemphasized.

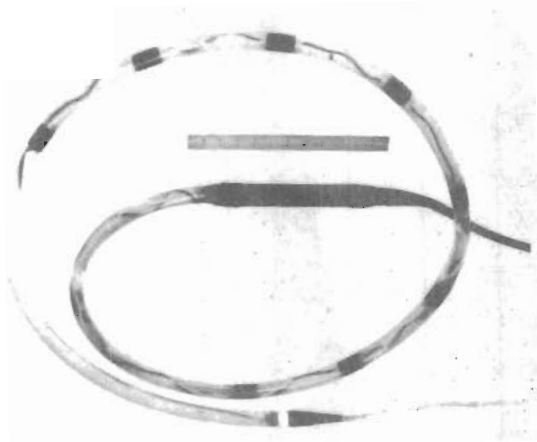
One of the most difficult problems with analysis and interpretation of a large number of seismic records is their printout length and width. The records are normally 19 inches (48 centimeters) wide, and even with considerable vertical to horizontal scale exaggeration, a typical survey with several hundred kilometers of trackline coverage yields several rolls of long records. Because



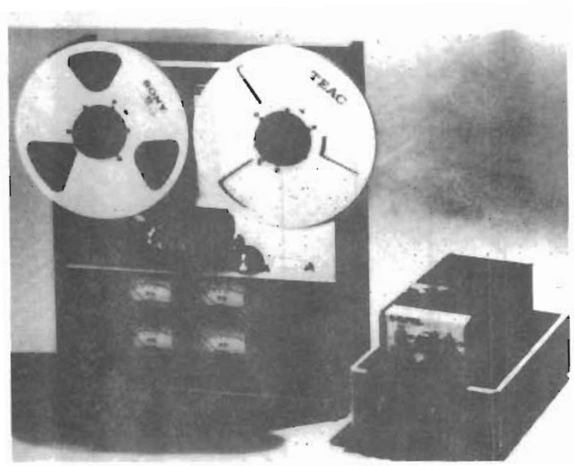
Graphic recorder



Energy source



Hydrophone



Tape recorder and amplifier-filter

Sound source catamaran

Figure 3. Components of EG&G Uniboom system.

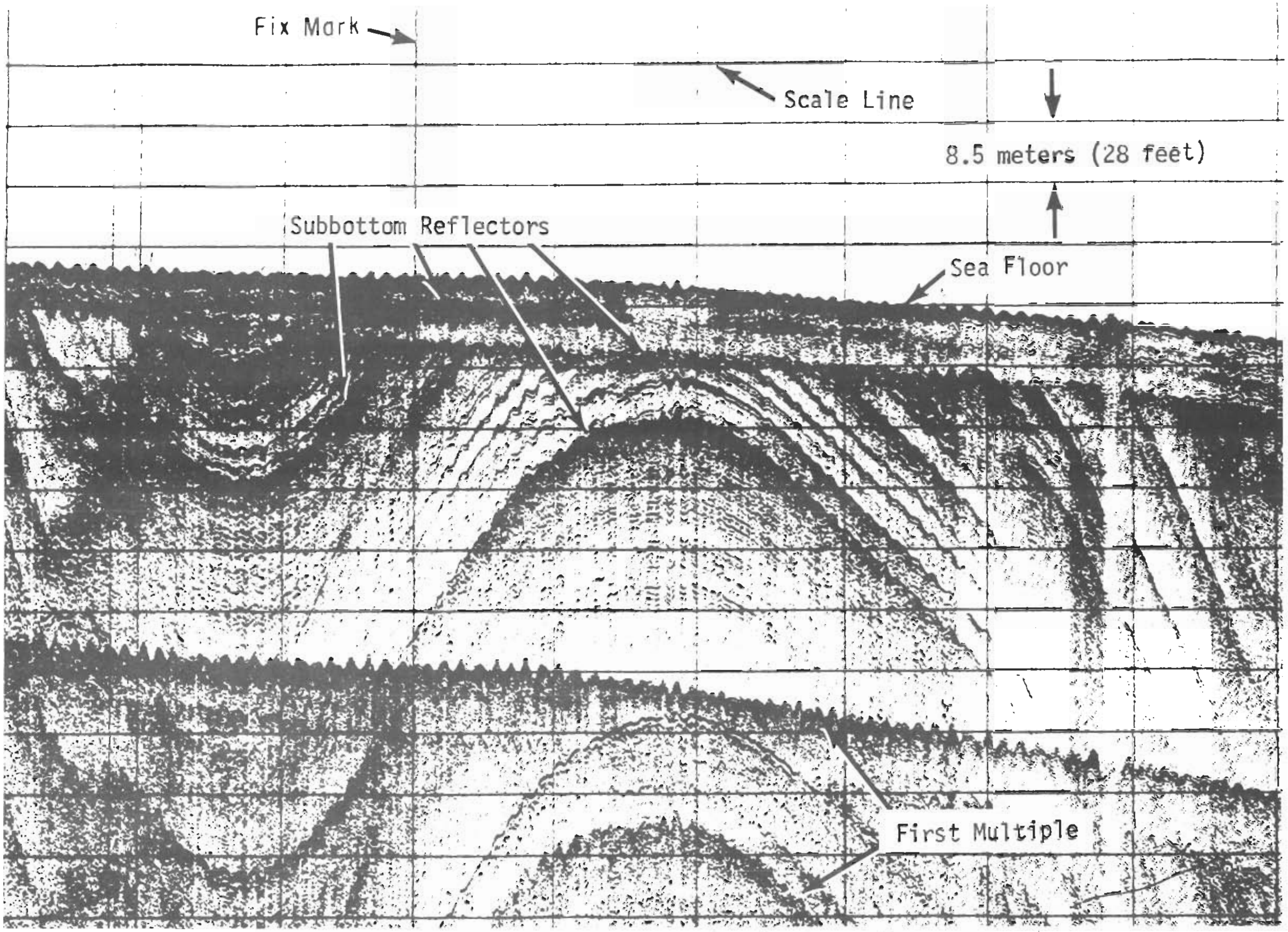


Figure 4. Example of Uniboom profile showing Holocene age sandy sediments overlying folded consolidated bedrock.

of the length of the records, considerable table space is required to lay out two or more records side-by-side to make comparisons. At CERC, specially built tables approximately 30 feet long are used for laying out the profiles for analysis and plotting. Also, to reduce the space problem and to provide a working copy of the records, a Xerox 1860 machine is sometimes used to reduce the profiles onto roll paper. The degree of reduction varies with each survey and with the type of profile, but a 50-percent reduction is generally satisfactory. The vertical detail may become too small or the fine character of the stratigraphy lost if too much reduction is made.

A difficulty arises when the survey tracklines are laid out in a box-grid configuration--the parallel lines appear with opposing ship headings; therefore, the subbottom features on the profiles are reversed. This condition makes comparative interpretations between lines difficult. Until recently, this was an unavoidable problem for the individual who interpreted the records, but now the latest recorders have the facility to reverse the record in real time so the recorder operator can insure all parallel line records print out in the same direction. Individuals involved in profile interpretation may not have a different preference for profile orientation, but by convention east should be the right for east-west tracklines, and south to the right for north-south tracklines.

Additional problems may be encountered when operating seismic systems in relatively shallow water, as is often the case for nearshore surveys. If water depths are less than the depths of subbottom penetration, the multiple reflections from the sea floor and strong subbottom reflectors will be superimposed on the profile and may partially mask the real data return. Masking by multiples is not as great a problem for boomer systems as for other systems, but even so the minimum water depth survey limits are about 15 feet (5 meters).

As part of the interpretation process, the important geological features and acoustical reflectors are marked and identified on each of the profiles. These are then placed on interpreted profiles or cross-sectional plots of the most important seismic lines; information from sediment samples may also be included. Along with the cross-sectional plots, the geological information is also displayed on different types of maps. The maps usually include bathymetric maps containing detailed morphology of the study area by means of depth contours. Isopach maps showing the thickness of unconsolidated sand and gravel resources, as well as any fine-grained overburden present, can also be made from the seismic data. Other maps of value are structure contour maps of important geological reflectors or surfaces beneath isopached units; surficial sediment distribution maps showing grain-size distributions and sedimentary contacts; and geological feature maps that display a variety of information, such as buried stream valleys, fault traces, pipeline routes, bedrock outcrops, sand wave and shoal areas, and areas of the seabed where there is evidence of erosion or deposition (Ploessel, 1978).

IV. SIDE-SCAN SONAR EQUIPMENT

1. Background and Principles of Operation.

The development and the commercial availability of side-scan sonar equipment are a major breakthrough for marine geology. The records or sonographs are somewhat analogous to a continuous series of oblique aerial photos. The principles of how side-scan sonar equipment works are similar to those of echo sounders. For echo sounders, as well as other acoustical seismic devices, the acoustical energy is directed downward toward the sea floor along a vertical axis; whereas, for side-scan sonar the very narrow acoustical pulses are directed in opposing directions from the towfish transducers at an angle of about 10° below the horizontal axis (Fig. 5). Side-scan sonar equipment was developed during World War II to locate and identify enemy submarines. However, researchers realized during field trials that the equipment was also capable of distinguishing between major sediment types, and capable of locating underwater objects with negative and positive relief from the sea floor, such as rock outcrops, sand shoals, channels, and wrecks (D'Olier, 1979). The first side-scan sonar built strictly for scientific use became commercially available in 1962 from the British firm, Kelvin Hughes, Ltd. (Flemming, 1976). During the past 20 years, a number of companies have continued to refine and develop their own side-scan sonar equipment. Today, there are a half-dozen systems available that are capable of giving good results. The major differences are: frequencies used that determine record resolution, the selection of range scanning widths, and more recently the availability of mapping unit recorders, which can yield true scale mosaics of the sea floor.

Most of the recent side-scan sonar units use piezoelectric transducers that vibrate at precise frequencies when electrical power is supplied. The vibrations from the transducer create pressure waves that are transmitted through the water column, reflected and backscattered from the seabed, and finally picked up by the hydrophone and recorded on continuous chart paper (Fig. 6).

The transducers for side-scan surveys can be either attached to the hull of the survey vessel where they can scan only in one direction and records may be distorted by ship motion, or the transducers can be mounted on a towfish that is pulled at varying depths astern (Fig. 5). This alternative allows for dual-channel scanning on both sides and also enables the operator to vary the tow depth above the sea floor to achieve optimum data return. Transducers usually vibrate in the frequency range of 50 to 500 kilohertz; however, the most commonly used frequency of about 100 kilohertz offers a compromise between maximum range coverage and good resolution of features on the seabed. The relatively new high frequency transducers (500 kilohertz) are most useful for short range, 150 to 450 feet (46 to 138 meters), scan coverage where the maximum resolution and clear definition of detail is desired. The lower frequency systems are better utilized in regional surveys where wider scanning paths on the order of 1,000 to 1,300 feet (305 to 396 meters) total width are desired (Fig. 7) (National Oceanic and Atmospheric Administration, 1976).

2. Operation of the Equipment and Sonograph Interpretation.

As stated, it is important prior to surveying to clearly define the desire objectives. For side-scan data collection, there is always a trade-off between the width of the coverage for each transect and the degree of resolution of features on the seabed. For detailed site surveys it is desirable to have a trackline spacing such that the sonograph records can fit into a mosaic to produce a plan view of the survey area with no gaps. Such an integrated view of the study area can greatly aid in identifying complex topographic features.

If a towfish-type transducer is used, the best results are achieved when it is towed above the sea floor at 10 to 20 percent of the range scale used. Thus, in surveying areas of high seabed relief the position of the towfish must be adjusted by altering the length of the cable used for towing. In all surveys,

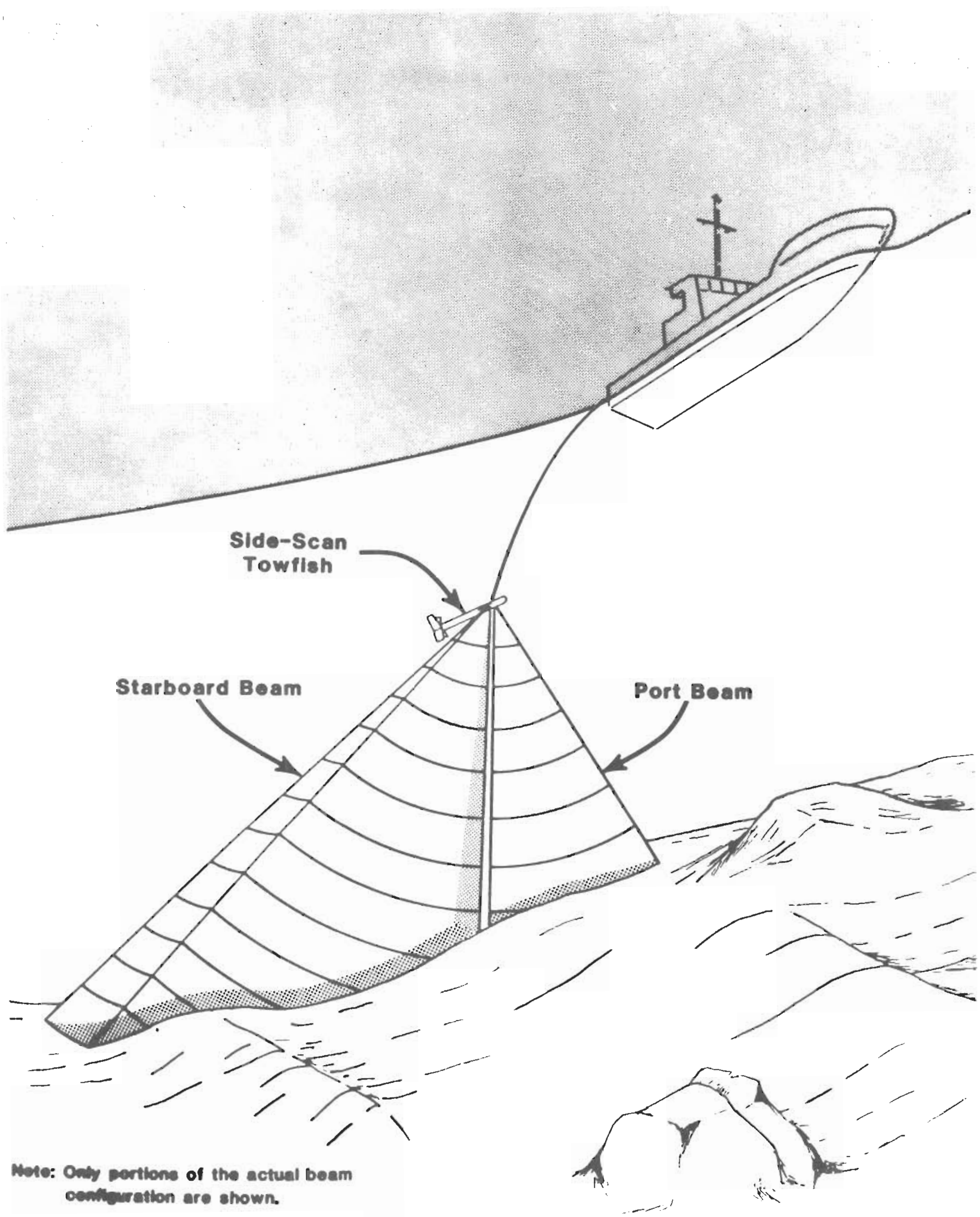


Figure 5. Schematic showing side-scan sonar using a detached towfish (from McClelland Engineers, Inc., 1981).

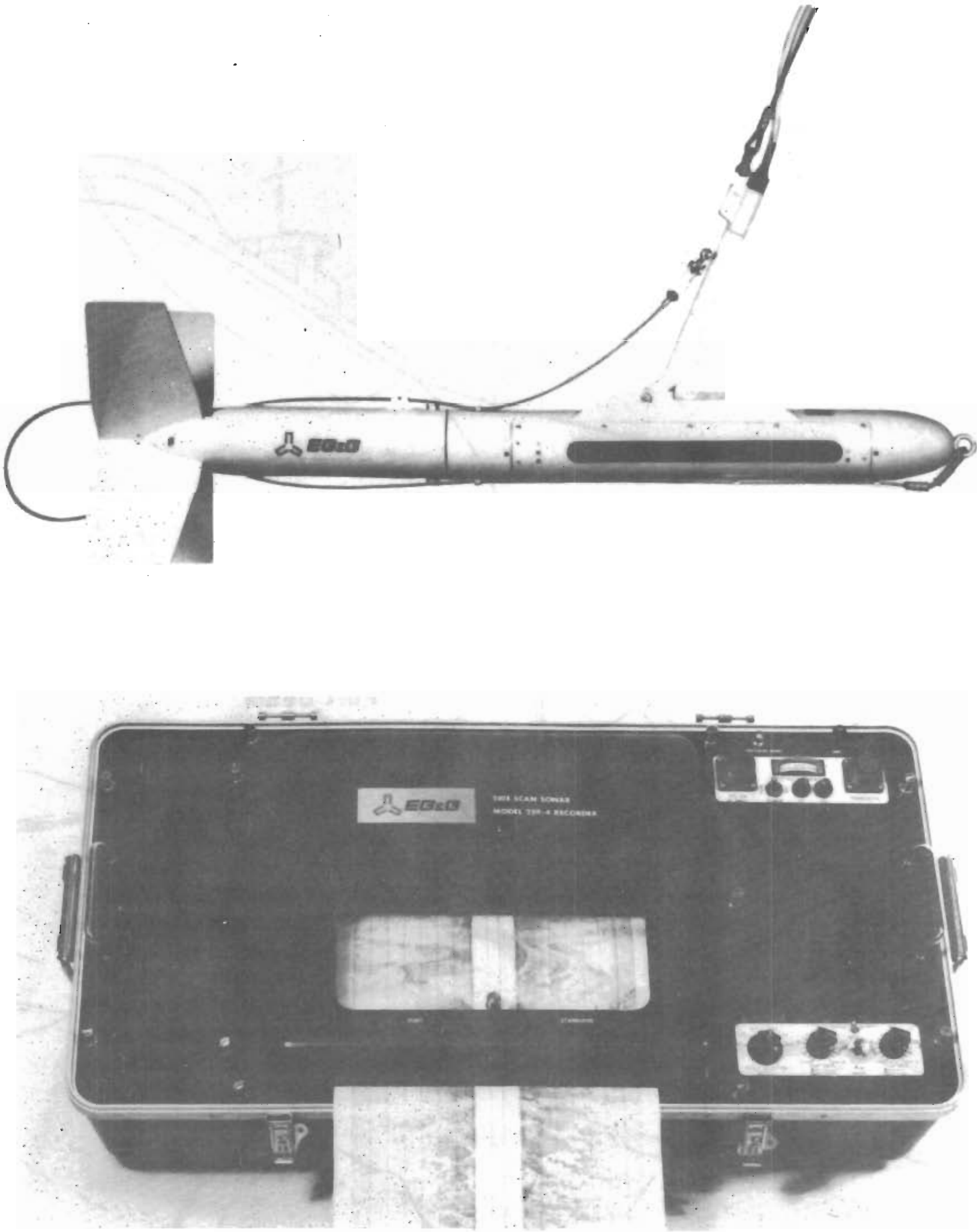


Figure 6. Components of EG&G side-scan sonar--towfish and graphic recorder.

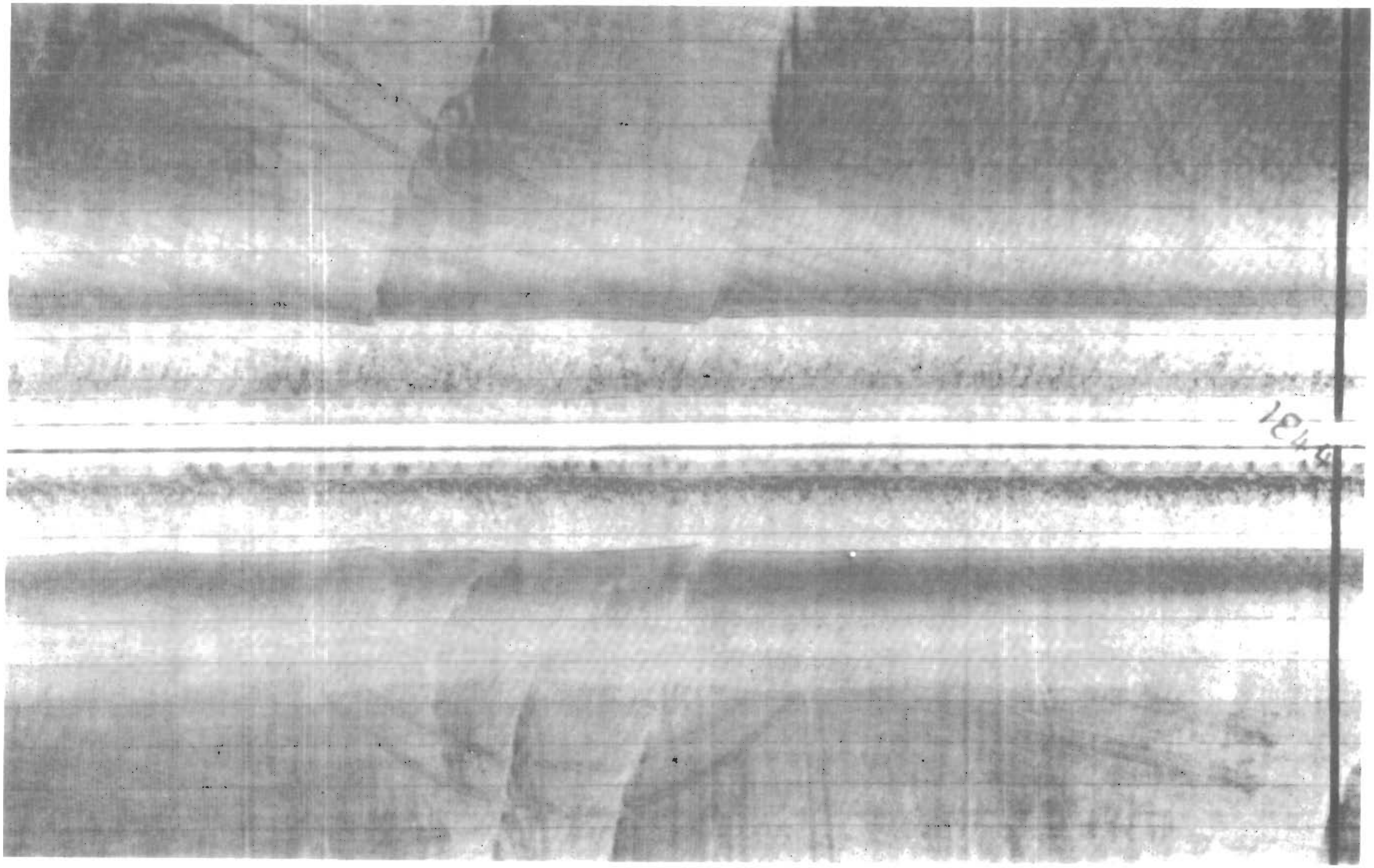


Figure 7. EG&G 100-kilohertz side-scan sonar record showing several straight and curving trawl marks traversing a sand-wave field.

it is important to maintain a constant vessel speed throughout the survey; the maximum speed should be about 5 knots; about 2 knots is best if very high resolution is important. Tow speeds greater than 2 to 5 knots decrease the number of pulses hitting "targets" in the survey area. Consequently, resolution will be reduced and smaller objects on the bottom may be missed altogether. Also, with higher vessel speeds the distortion of objects on the record becomes a problem. Objects are compressed parallel to the path of travel at vessel speeds greater than about 2 knots. At 5 knots compression is about 50 percent of the real size in the ship-path dimension.

Until recently, all side-scan sonar records gave a somewhat distorted view of features on the sea floor because differences in the tow speed and recorder speed yielded records with different scales in both horizontal directions. However, microprocessor mapping units from several manufacturers are available which give scale-corrected or isometric records with constant scales in both directions. These new mapping systems are important for surveys where very accurate target dimensions and geographic positions are required. For most surveys the conventional side-scan sonar provides sufficient accuracy.

Successful and accurate interpretation of side-scan sonar records is an acquired skill that is based on experience and judgment as much as on training. Training is required in the beginning to understand the physics of how the systems function, but the interpretation of the sonographs depends mostly on distinguishing between tonal intensities and relating target shapes to scaled-down geological features. This expertise is developed through experience in examining records ideally from well-known sea floor areas where sediment samples, bottom photography, or diver observations are available.

When the sonar signal is transmitted it is attenuated and scattered somewhat as it travels through the water, and further energy losses occur when the pulses strike the sea floor. The intensity of the returning signal will determine the tonal shading on the sonogram. Intensity is largely dependent on the composition and porosity of sediment on the seabed, as well as the bottom topography. Relationships between tonal intensity and sediment characteristics are not fully understood, but in general, the denser and coarser the sediment, the greater the reflectivity, and consequently the darker the tone on the sonograph. Therefore, outcrops of dense bedrock on the seabed will have very high reflectivity and be the darkest; gravel patches will be darker than sand, and sand will be darker than fine-grained muddy sediments. It is important to bear in mind that there is an inverse relationship of acoustical impedance to sediment porosity. High porosity sediment (e.g., clays ~75 percent) has a relatively low impedance and low reflectivity and appears light on sonographs; whereas low porosity material (e.g., medium sands ~40 percent) has higher impedance, higher reflectivity, and appears as darker tones. However, porosity does not depend solely on the grain size; other factors such as grain shape, degree of sorting, and sediment compaction can cause sediments of different sizes to be similar in porosity and therefore have very similar tonal shades.

The topography of the sea floor also affects reflectivity and may cause effects on the records similar to changes in sediment composition and porosity. Slopes on sand waves and ridges, and projections such as boulders and outcrops that face the outgoing acoustical signal will give a strong reflection on the near side of the record, but they will also produce a pronounced acoustical shadow on the far side, where no signal is reflected and a white area is produced on the sonograph. In addition, the height of objects above the sea floor can be calculated from side-scan records if the length of the shadow is known, along with the height of the towfish above the seabed (D'Olier, 1979).

An important aspect of side-scan sonar interpretations is being able to distinguish between "real" or "meaningful" reflection returns and the interference from various sources. There are three major sources of interference that may be expressed on the records:

(a) *Continuous interference* results from operating other seismic equipment simultaneously with the side-scan. The benefits of running several instruments at the same time during surveys far outweigh any interference problems, and often the problems can be minimized by towing the instruments farther apart and making adjustments to fine tune the recorders.

(b) *Discontinuous interference* is usually very obvious when it appears and is usually associated with wake waves from passing ships.

(c) A third type is caused by schools of fish or dense concentrations of suspended mud in the water column. The acoustical signal is partially dispersed or reflected before it reaches the sea floor. This results in light areas across all the ranges; whereas dark areas appear in the depth profile.

Whenever interference artifacts are recorded during a survey, the technician operating the recorder should note their occurrence on the records. This will insure that the person interpreting the data later is not confused.

V. SUMMARY

In the past three decades, great technological advances have been made in the development of continuous seismic reflection and side-scan sonar equipment for use in geological and engineering studies of marine, estuarine, and lake environments. Various types of acoustical equipment are available that vary in frequency and power and must be carefully matched to the objectives of any survey. For the past two decades CERC has conducted 18 surveys and collected about 10,000 track miles (16 093 kilometers) of seismic profile data over the Atlantic, Gulf of Mexico, and Pacific Continental Shelf areas, as well as in Lake Erie and Lake Michigan to locate and inventory resources of sand and gravel and describe the geological character of each region. Experience from these surveys regarding use of geophysical equipment is summarized in this report.

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